Simulation of Pulse-Plating in High Aspect Ratio Trenches

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Introduction

Electrochemical deposition of Copper is one of the most important steps in the metallization processing for on-chip interconnections in the semiconductor industry. Void-free filling of trenches and vias can be achieved through two different ways: by adding additives to the bath that exert control on the deposition kinetics, or by using pulse plating. In pulse plating a current waveform (pulse plating followed by an off and/or a reverse period) may be applied to the cathode and the current is switched on during the deposition period. Depending of the waveform a greater control of the bath concentrations can be obtained leading to a more uniform plating rate. Previous studies exist on pulse plating in trenches[1] and reverse-pulse plating[2,3]; these include either 1D models or "quasi–steady" models.

In this work a mathematical model is presented to predict the shape evolution during pulse plating of copper in trenches with high aspect ratio taking into account the transient character of the phenomena involved at time scales less than the diffusion time. In a previous work[4] a mathematical model for copper electrodeposition in trenches in the presence of additives under quasi steady-state mass transport was presented. In this case, the model addresses the complete transport balance in transient electrochemical systems involving moving boundaries. Study of pulse and pulse-reverse plating including various waveforms was possible. The influence of the throwing power, duty factor and pulse duration on shape evolution in such geometries is also investigated. In addition, the influence of solution composition on the deposit profile is numerically identified. The model was implemented to explore processing conditions for void-free plating.

Mathematical Model

The continuum model of the electrochemical systems of interest consists of coupling the associated species balances with electroneutrality for the solution potential. The transient transport equation includes diffusion, migration and convection. Appropriate initial and boundary conditions complete the mathematical formulation of the case under study. The duty cycle of the process determines plating, no-plating and reverse plating (where applicable) intervals during the pulse period.

FIDIPIDIS, a general purpose finite difference method for transient deposition and dissolution processes in interconnection features such as trenches and vias, is used for solving the continuum equations. The code incorporates a multi-block adaptive grid generation technique for the discretization of the physical domain and simulates shape evolution using adaptive meshing capabilities. Because the duration of pulses can be smaller than the diffusion time inside the trench, the moving boundary simulations implements transient mass transport state, i.e. the concentration transients relaxes slower than the moving of the electrode boundary.

Results

FIDIPIDIS was applied to the problem of copper pulse and pulse-reverse plating inside trench geometries of high aspect ratios. The resulting profiles of plated copper depend on bulk composition and pulse waveform parameters such as applied potential, pulse duration and duty factor. The model was then used to identify the processing conditions for void-free pulse plating.

Conclusion

We developed a numerical model that can predict shape evolution for pulse and pulse-reverse plating. This model can handle transient transport by diffusion, migration and convection, and a variety of boundary conditions and pulse waveforms.

References

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